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Grid code status for wind farms interconnection in Northern Africa and Spain: Descriptions and recommendations for Northern Africa

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ABSTRACT

Electricity production from renewable energy sources is increasing as costs are going down and concerns of climate change are driving political targets to shift away from fossil fuels. The fast expansion of renewable energy into the electric grid, from being negligible to becoming important for system stability, has implications for grid planning and operation. In this situation, grid operators need to ensure that the grid continues to operate in a safe, secure and economic way. To achieve this, grid codes have been introduced as common rules that regulate these responsibilities; and define standardized and transparent requirements for any facility connected to the grid. This paper gives a review of the status of grid codes in Northern Africa and Europe. It describes technical grid connection requirements particularly relevant for renewable energy integration with a focus on wind energy in general and more in-depth for Spain, Morocco and Egypt. Challenges regarding grid code standardisation and grid code compliance of renewable energy are addressed, and recommendations for further development of grid codes in North Africa are made, building on experiences from Europe.

1. Introduction

Renewable energy generation has increased significantly, in the past few years, to constitute an important proportion of the total energy generation in the electric grid. The high share of these intermittent generation sources causes several issues to the utility grid. To ensure grid stability, various challenges must be addressed. Studies and experience in recent years have revealed new technical solutions needed to overcome these difficulties. Solutions include new methods and practices that should be applied in order to provide more flexibility and improve the efficiency of the electric system.

However, it is not only the high share of renewable power that is calling for stricter requirements; it is also due to the advance in technology that inquires stricter requirements. An example for a technology triggered change of requirements is to have a wide range of reactive power control. For the case of wind turbines, this is made possible with the introduction of an interface between wind turbine generator and the grid via power electronics. Reactive power and voltage can be controlled more accurately and easily with modern wind turbines (full scale back-to-back converter or doubly fed electrical machine), compared to regular induction generators directly connected to the network. This new requirement can significantly support the grid voltage stability.

The integration standard of renewable energy currently exits at the national level or grid company level. Several counties are updating their grid code, or developing standards' documents, based on experiences learned from other countries. These include requirements or guidelines to meet the increasing penetration of renewable energy generation. Sometimes, grid code requirement for generators are general and applicable independently of generator types. Other times, special grid codes are made for the particular renewable energy source, e.g. wind and photovoltaic generation.

Grid codes are often similar in different countries because they have the same general objectives. Example of requirements that are included in most of the wind power plant interconnection standards are [1]:

- Voltage range for continuous operation.
- Frequency range for continuous operation.
- Low voltage ride through.
- Active power set point and ramp rate control.
- Reactive power control and voltage regulation.
- Power quality such as flicker, harmonics and voltage fluctuation.

Grid codes may be different among countries due to: the way grids

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are managed in each country, different features and development stages of renewable energy generation, different characteristics of the power system, as well as different grid companies. These standards may differ in their contents and particularly in the specific values of some requirements.

Grid code requirements for renewable energy plants especially large wind farms has been explored in the literature. The United States regional and federal grid code was examined in [2]. Grid code regulations for Canada, Spain, Ireland, Germany, and UK were discussed in different countries by authors in [3–7]. In [8], authors compare grid code requirements in Germany, Denmark, UK, and Ireland. Other comparative studies for different international grid codes were presented in [9–11]. The harmonisation of international grid codes and the expected future trends in the regulations are also discussed in [11].

A more comprehensive comparison of grid codes for several countries was presented in [12]. These countries include Germany, Belgium, UK, Ireland, Canada, Sweden, Denmark, New Zealand, USA, Spain, and Norway. Another review of recent grid codes for different countries is studied in [13]. Authors in [14] present a review of both grid requirements and control methods, necessary for the participation of wind turbines in synthetic inertia and system frequency control. Grid code modifications for the implementation of renewable sources in insular energy systems were discussed in [15]. A major update of current grid requirement is essential for a safer shift towards sustainable energy generation. To ensure future grid stability, it is important to introduce control and regulation capabilities to renewable energy sources [15].

In this paper, we extend the literature by discussing the status of grid codes in North African countries and in Spain with a focus on wind energy. Concerning grid code for other renewable systems such as PVs, only few countries have elaborated technical requirements regarding PV installation. A discussion about these requirements in Spain is presented in Section 3.1. However, up to date, Morocco and Egypt have not elaborated such grid codes. As for the requirements for the solar thermal and biomass, renewable energy generators, these are considered as being similar to conventional thermal systems. This is the reason behind our focus on wind energy. Recommendations for further development of grid codes in North Africa are also proposed.

This paper is structured as follows. Section II discusses the status of grid code development in Europe and North Africa. A discussion about technical grid connection requirements for generators in Spain, Morocco and Egypt is presented in section III. The different technical requirement for the interconnection of wind farm in Spain, Morocco, and Egypt are compared in section IV. Section V, explores the barriers facing North African Countries and provides recommendations on the development of grid codes for renewable energy integration in these countries. Finally, section VI provides a summary and some concluding remarks.

2. Status of development

2.1. Grid codes in Europe

Grid codes in Europe were generally developed together with the unbundling process in the energy sector; whereby previous state controlled monopolies were divided up and shared responsibilities for production, distribution and supply were defined. The amount of detail included in the codes, however, vary very much from country to country.

The process to address the special characteristics of renewable energy generation has been driven largely by the development of wind power. In the 1980s, wind power enjoyed an exceptional treatment when it comes to grid connection requirements, as it was not system relevant. However, during the 1990s wind power development gained momentum, while the old regulations still were in place, disregarding system relevance aspects of wind power. This mismatch has led to large amounts of wind power connected to the grid; following requirements which were not suitable for large scale implementation. Eventually, this resulted in a significant threat for stable grid operation, consequences of a major disturbance became even more severe due to the contribution of wind power. The Irish moratorium on grid connection of wind power, in 2003, is an example of unfortunate consequence of inadequate grid code requirements.

The rising total share of wind power and the continuously growing system relevance, have been the reasons for the extension and adaptation of grid codes to include wind power generation. Thus wind turbine manufacturers and wind power plant developers were given stricter requirements. The most relevant requirement that has evolved is that wind turbines have to stay connected to the grid during disturbances, i.e. fault ride-through capability.

Currently, the European Network of Transmission System Operators for Electricity (ENTSO-E), which is an umbrella organization for European Transmission System Operators (TSO), is developing a set of network codes that will be implemented as European Law. These network codes define a common language and format; and are a contribution towards harmonisation of grid codes within Europe.

2.2. Grid code in North Africa

Grid codes for generation units in many North African countries are determined on a case-by case basis. There is therefore a need for standardized grid codes in order to simplify the grid connection planning process. Currently, the general approach is to base the requirements on European grid codes, with appropriate modifications.

The electricity sector in the North African countries differ, and reflect each nation's market structure. A summary of current national market structures, institutions and regulations are given in Table 1 for Algeria, Tunisia, Libya and Egypt. In addition a brief description follows for each mentioned country.

Table 1
Current national market structure, institutions and regulations.

	Algeria	Egypt	Tunisia	Libya
Reform	Under way with new law passed	Limited	Limited	None
Market structure	Single buyer with unbundling	Vertically integrated under the Egyptian Electricity Holding Company	Limited	Vertically integrated
Separate regulator	Yes	Yes, but without responsibility for tariffs	No	No
Open access	No	No	No	No
Grid code/distribution code	Yes/yes	Yes/no	No/No	No/no
Private sector participation	Yes, in generation and distribution	Yes, in generation	Yes, in generation	No
Tariffs	Subsidized	Subsidized	Subsidized	Subsidized

2.2.1. Algeria

On February 2002, with the approval of Law no. 02-01, the Liberalization of Algeria's electric sector has begun. The law contains requirements for unbundling the former vertically integrated utility, SONELGAZ; market model and participant responsibilities and roles [16]. Algeria has developed a single-buyer market model with the transmission grid planning and operation governed by the independent system operator (ISO) that is represented by SONELGAZ/OS. Four independent power producers (IPPs) with international ownership also took part in the Algerian power market. In addition, there are four distribution companies located in separate geographic regions across the country. Renewable energy and energy efficiency has been emphasized by the government. At present, renewable energy sources represent only a small proportion of the total energy generation. Algeria plans to develop 2570 MW of renewable generation by 2020 and 12,000 MW by 2030 [16].

2.2.2. Egypt

The electricity sector in Egypt is controlled by the Ministry of Electricity and Energy. This governmental organism is responsible for the development of polity and the implementation of government decrees. The Electricity Utility and Consumer Protection Regulatory Agency is responsible for supervising the electricity sector. Its role is to enhance the operational, financial, technical and practical organisms of the electricity business. A schematic of the electricity sector is illustrated in Fig. 1 [16].

The electricity sector consists of executive authorities that are in charge of a specific mechanism of the electricity sector. The daily operations of the electricity sector which consist of generating, transmitting and distributing energy are carried out by the Egyptian Electricity Holding Company (EEHC) and its partners. The generation division consists of six companies owned by the government which include hydropower plants, renewable energy system plants, and four other companies classified by geographic area, comprising Cairo, West Delta, Upper Egypt and East Delta. In addition, in the generation sector, there are three other private companies with six IPPs. The transmission activities are managed by the Electricity Transmission Company that is owned by the government and acts as a single buyer of all generation. Energy is sold by the transmission company to nine regional distribution companies that are state-owned. Hence, this country has a single-buyer market model with elements of a monopoly model under the Egyptian Electricity Holding Company.

2.2.3. Tunisia

The generation of electricity, transmission and distribution has been supplied, till 2002, by one state owned, vertically integrated monopoly, company known as STEG (Société Tunisienne de l'Electricité et du Gaz). In 1996, the monopoly of STEG's has been ended by the Tunisian government to support private power generation. In 2002, a combined-cycle plant producing 471 MW at Rades started operation and was the first IPP. Two years after, the second IPP has also started operation. The most important participants in Tunisia's power sector today are STEG and the two IPPs. Fig. 2 illustrates the organization of Tunisia's energy sector.

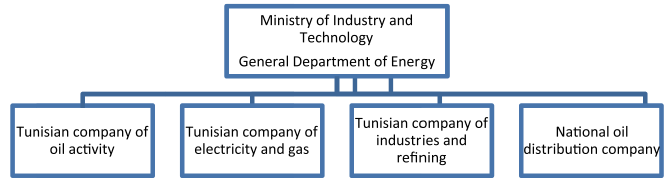


Fig. 2. Organization of Tunisia's Energy Sector.

This country developed a strategy for the promotion of renewable energy sources starting 1985. Relative to its neighbours, Tunisia has been early in shaping a progressive energy management strategy. In 2009, a solar plan was implemented in Tunisia with a purpose to increase the share of renewable energy systems and energy efficiency.

2.2.4. Libya

The energy generation, transmission and distribution are owned and controlled by the General Electricity Company of Libya (GECOL) which is a vertically integrated monopoly. The power sector is hence governed by GECOL as it is in charge of planning, policy, and regulation. Therefore, an independent regulatory authority does not exist in Libya's power sector. In response to the rapidly growing energy demand, Libya has launched an aggressive generation and transmission expansion plan. The country has an ambitious plan to install generation capacity of 13,000 MW by 2020 [16]. In addition, to transmit the new generation to locations with increasing demand, Libya has started several transmission projects. These plans comprise studies for the expansion of international interconnections. At this time, the power sector's main role is to guarantee secure and sufficient supply of power to every part of the country. The objectives of Libya are to reduce technical and nontechnical losses, to develop service quality and efficiency and to reinforce interconnections with nearby countries.

2.2.5. Morocco

The power sector of Morocco consists of private and public operators. The main players include the Office National d'Electricité (ONEE), independent power producers (IPPs), and the distributors.

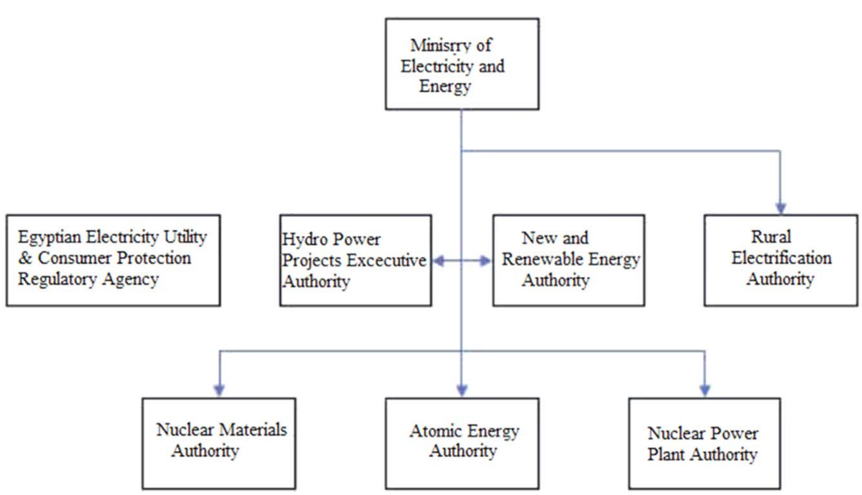


Fig. 1. Structure of Egypt's electricity sector.

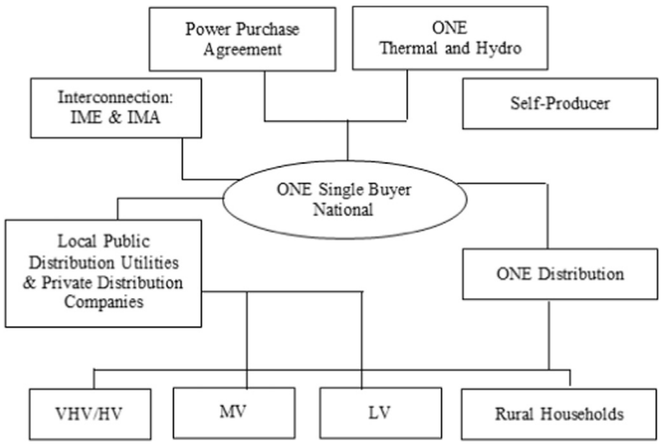


Fig. 3. The organization of the Moroccan Power Sector. IME=Interconnection Morocco–Europe; IMA=Interconnection Morocco–Algeria.

The principal role of ONEE is to operate and manage the transmission grid of the country, part of the distribution network, and its generators. ONEE holds power-purchase agreements (PPAs) with private producers.

Morocco's distribution sector includes both public and private companies. The electricity market activities are regulated by several ministries which include the Ministry of Interior, the Ministry of Energy and Mines, the Ministry of Economic Affairs, and the Ministry of Finance. According to Law Dahir 2–94–502, Morocco has a single-buyer market model. All generated power in Morocco is purchased by ONEE through power-purchase agreements. ONEE is also responsible for importing power from Algeria and Spain. The Moroccan power sector is organized as illustrated in Fig. 3.

To consider progress and allow for changes, Morocco has to make some regulatory and legal adjustments. Currently, Morocco does not have an independent regulatory authority. In addition, there is no published transmission tariff for making access to the transmission system. However, the country is working on a reform that will create a free market which will function in parallel with the regulated market. The Moroccan government supports renewable energy through various laws, met through a number of projects with targets relating to energy security and development [17].

3. Grid code requirements in Spain, Morocco and Egypt

In this section, requirement for generators encountered in different grid codes will be discussed.

3.1. Spain – wind and solar power plants

The development of renewable energy technologies and green energy solutions involves both the governmental incentives towards these installations, but also the appropriate regulatory framework where the connection requirements are summarised. Generally, grid codes are demonstrated to satisfy the operational limitations and ensure the system security.

As far as the technical recommendations for special regime generation are concerned, emphasis is rather paid on wind power plants, however only few countries, like Spain Germany and Italy have elaborated technical requirements regarding PV installations. Fig. 4 shows the different limiting curves of voltage at the grid connection point for PVs in Spain, Germany and Italy, respectively. The German and Italian grid codes are stricter and more demanding since PV installations have to attend voltage dips deeper and shorter without tripping.

In Spain, grid codes that concern wind power integration support that during faults, wind turbines must continue being connected

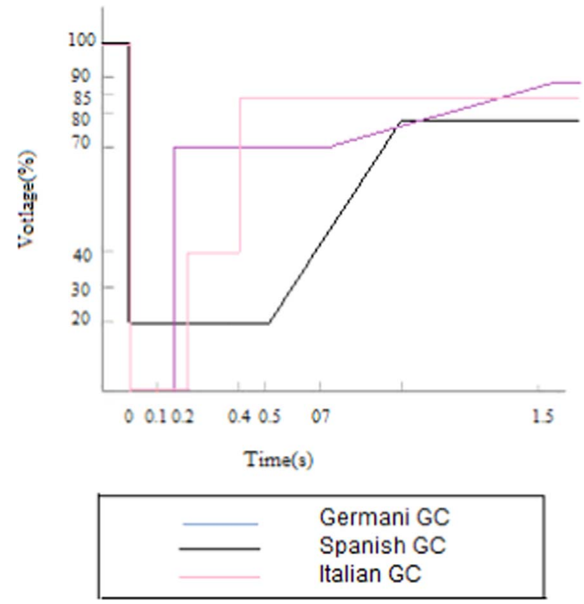


Fig. 4. Voltage limiting curves at the grid connection point for PVs.

permitting the protection system to clear the fault [18]. Wind power penetration at the distribution level mainly concerns local power inefficiencies. One of the major issues is to keep the steady-state nodal voltages within their acceptable limits ($\pm$ 5%). According to this reference point, wind integration in distribution level has to encounter the RD 436/2004 as appears in MITYC in 2004 [19,20]. “Metodología para la actualización y sistematizacióndelrégimenjurídico y económico de la actividad de producción de energíaeléctrica en régimenespecial”.

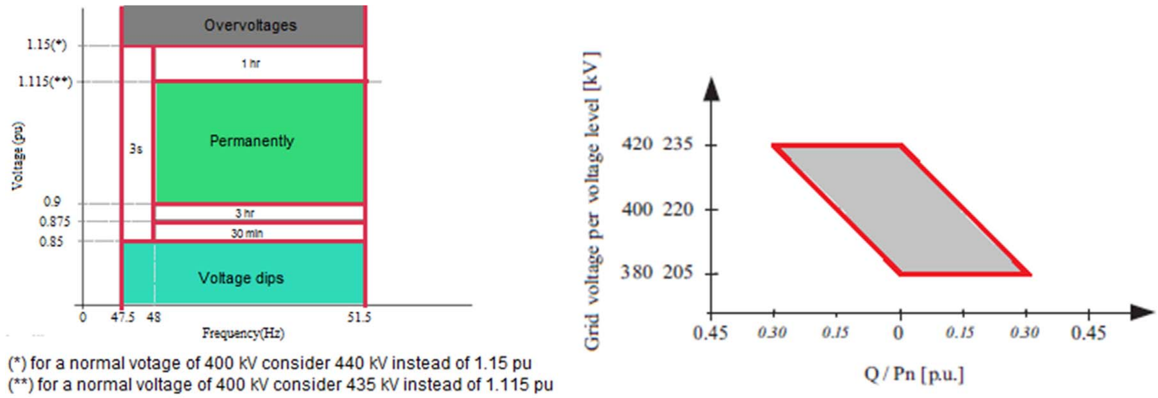
The Spanish System Operator, Red Electrica de España (REE), has numbered various technical specifications, like the Operation Procedure which was approved in October 2006 as “Requirements for response to voltage dips of production facilities under the special regime” (P.O.12.3) [21]. P.O.12.3 refers, mainly, to the acceptable voltage dips at the interconnection point with the transmission/distribution grid of a wind farm after a short circuit fault without tripping. These disturbances include both balanced and non-balanced faults; mainly due to single-phase-to-ground, two-phase to-ground and three-phase short-circuits.

However, a first draft of a new proposal, P.O.12.2, was launched in 2008 and then its updated version in 2010 under the title: “Technical requirements for wind power and photovoltaic installations and any generating facilities whose technology does not consist of a synchronous generator directly connected to the grid” [22–25]. The updated text is not only orientated to wind but also to PV power plants with a capacity greater than 10 MW and differs from the previous calls in the voltage-time characteristic according to the type of fault, while it is in effect since 2011. Additionally, this call requires for the first time a voltage controller for defining the reactive power support during voltages outside the normal operation range [26].

3.2. Performance under normal operation

3.2.1. Voltage and frequency

According to the Spanish regulation RD 661/2007, the nominal frequency is 50 Hz and it allows a wide continuous frequency range of 48–51.5 Hz. For instance, the wind farms may stay coupled to the grid for frequencies below 48 Hz no more than 3 s (P.O.1.6). The disconnection time for over frequencies ($>$ 51.5 Hz) has to be agreed with the TSO. Wind Power Plants (WPPs) also need to operate with a range around the rated voltage. Fig. 5a represents the minimum periods that the plant must remain connected to the grid under variations in voltage/frequency during normal operations and/or disturbances [19].



a) b)

Fig. 5. a) Voltage-frequency behavior, b) Voltage – reactive power correlation.

3.2.2. Active and reactive power

The Spanish normative takes into account the participation in secondary control via power curtailments. In more details, the WPP needs to reach any set-point defined by the TSO, in addition to this; it should state the difference among the actual and the rated power when it operates in attenuated mode.

On the other hand, the reactive power control prerequisites require wind power plants to regulate the output reactive power Q in response to grid voltage variation, also known as Automatic Voltage Regulation (AVR). In general, the reactive power requirement is usually given in three different ways:

- Q control: The reactive power should be controlled independently from the active power at the point of connection.
- Power factor control: The reactive power is controlled proportionally to the active power at the point of connection.
- Voltage control: It is a function, which controls the voltage in the voltage reference point by changing the reactive power generation.

It should be stressed out that the reactive power control and voltage control functions are mutually exclusive, which means that only one of the above three functions could be activated at a time [27].

Under voltage control mode and in case the voltage is outside the range of ± 5% of its nominal value, i.e. 0.95 or 1.05 pu, the installation injects/absorbs reactive power according to the voltage deviation and the reference point.

The requirements described herein concern high voltage values and are a function of the active power and transmission voltages as given beneath [28]:

- Minimum deviation of ± 15% of reactive power generation for all technical P range and nominal voltage.
- Minimum range of ± 30% of reactive power generation as a function of the voltage, as shown in Fig. 5b.

The voltage in an electrical system is regulated by all generators. The high penetration level of wind energy into the network requires an active participation from wind farms in voltage control scheme at the connection point, complying also with the TSO requirements.

The generators control the voltage through reactive power control. The direct relationship among the voltage difference and the reactive power is shown in the following equation:

$$\Delta V_{AB} = \frac{R \times P + X \times Q}{V_R} \tag{1}$$

As X > > R, the variations in reactive power affect at a higher rate the voltage drop than any variations in the active power P. This can lead to the disconnection of wind farms and may threat the system's power stability.

According to Real Decreto RD 661/200, the voltage control offers premium that ranges from −4% to 8% of 7.8441 c€/kWh to energy producers that operate for a power factor depending on the demand profile.

The RD. 436/2004 defines bonus and penalties for reactive power variable according to the time of the day (peak, medium and normal level) and expressed in percentage of the averaged price. The bonus can range from 4% to 6% if facilities maintain a unity power factor at the connection point. Table 2 represents the complement according the power factor and demand determination.

3.2.3. Performance under distorted regime

Grid disturbances like voltage sags or swells may lead to tripping of wind and PV power plants. In order to avoid this, grid codes requirements usually involve the following:

a) stay connected to the grid even if the voltage drops down to zero for up to 150 ms
b) contribute to voltage recovery by injecting reactive current
c) rise up the active power after the fault clearance

The typical features grid codes often call during fault incidents are the ones beneath:

a) Fault ride-through (FRT) capability, including both low voltage ride-through (LVRT) and high voltage ride-through (HVRT) of the system to recover to its pre-fault status, in addition to the time frame necessary for WPPs to withstand symmetrical and asymmetrical faults without disconnecting or even the conditions under which a disconnection from the grid in inevitable.

Table 2
Bonus according to power factor and load demand.

	Power Factor COS PHI	Peak	Medium	Low
Inductive	< 0,95	−4	−4	8
	< 0,96 & > 0,95	−3	0	6
	< 0,97 & > 0,96	−2	0	4
	< 0,98 & > 0,97	−1	0	2
	< 1 & > 0,98	0	2	0
	1	0	4	0
Capacitive	< 1 & > 0,98	0	−4	−4
	< 0,98 & > 0,97	2		
	< 0,97 & > 0,96	4		
	< 0,96 & > 0,95	6		
	< 0,95	8		

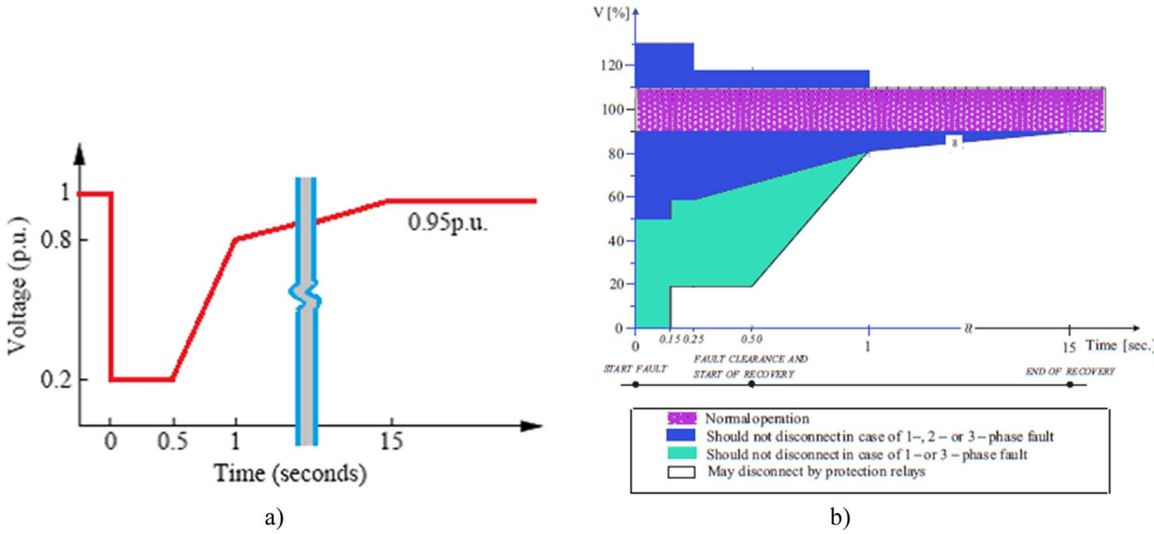


Fig. 6. a) Voltage behavior after a short circuit incident according to P.O.12.3., b) Time-voltage profile as defined in P.O.12.2 draft. Minimum voltage dips to be supported by PV & Wind power plants without disconnection.

b) P and Q limitation during faults and recovery.
c) Reactive current injection (RCI) for voltage support during fault and recovery.

3.2.4. Fault ride-through capability – LVRT and HVRT control

According to Spanish P.O.12.3, WPPs and PVs need to remain connected within the area defined by the graph as is shown in Fig. 6a. The voltage drop is characterized by a voltage decay followed by a voltage recovery in two ramps with different slope. This voltage decay rises up to 20% of the nominal value for the first 0.5 s, followed by a voltage enhancement divided in two parts: firstly from 20% to 80% of the nominal value in the next 0.5 s and one from the 80% to the 95% of the nominal value in a total time of 14 s. Additionally, in case of a double-line-to- ground fault the voltage nadir does not drop beyond the 60% of the nominal value [26,29]. The minimum value of 0.2 pu derives from stability simulations and the maximum active power that can be lost by the Spanish power grid when a fault occurs, whereas the time interval of 0.5 s for the voltage dip complies with the general protection criteria of the Spanish electrical system. Additionally, the voltage recovery indicated above results from the under-voltage protection of non-renewable generators and is activated for voltages lower than 0.8 pu.

According to P.O.12.2, the magnitude and duration of voltage dips for single-phase, two-phase to ground and three-phase faults are depicted in Fig. 6b. The low voltage ride-through capability states that wind and PV power plants need to tolerate 0% remaining voltage dips until 150 ms without going out of operation. Furthermore, the afore-mentioned plants should be able to stand a voltage swell up to 130% at the connection point.

In the particular case of a two-phase to ground disturbance, there exists a different voltage-time curve to characterize the voltage dips. According to Fig. 6b:

- No disconnection is allowed within the blue area for one-, two- and three-phase faults.
- No disconnection is allowed within the green area for one- and three-phase faults.
- During the whole transient regime, the facility must be able to inject to the grid at least the nominal apparent current.

Fig. 7 correlates the voltage-time characteristics for the different Spanish grid code procedures. The P.O.12.2 draft entails more demanding requirements since both wind and PV farms must support deeper and longer voltage dips, but is still more relaxing in the special case of two-phase to ground faults.

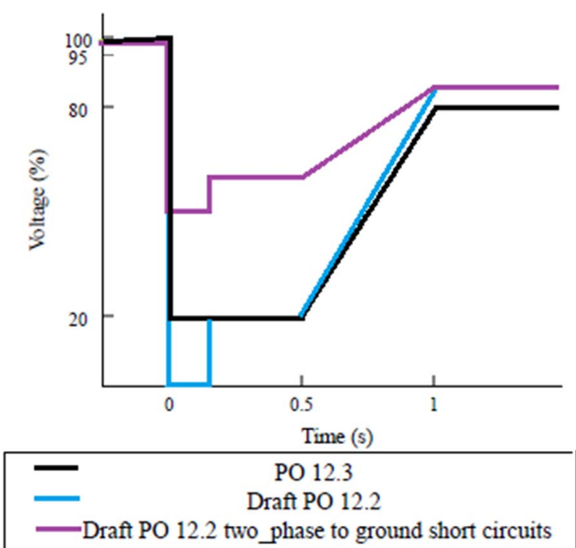


Fig. 7. Spanish grid code procedures: comparison of voltage-time limiting curves at the grid connection point.

3.2.5. P and Q requirements during faults and recovery

For both operational procedures, i.e. P.O.12.3 & P.O.12.2, the demand of active and/or reactive power is not allowed during periods of system failure and recovery following the fault clearance. All along the transient regime, the system needs to feed the grid with at least its nominal apparent power.

P.O.12.3 permits punctual consumption only when the conditions detailed in Table 3 and Table 4 are fulfilled [29].

As far as the P.O.12.2 is concerned there are some specific conditions which have to be met for the reactive and active power and are detailed below

- Momentary active or reactive power consumption (< 0.6 pu) is allowed during just the first 40 ms after the start of the fault and the first 80 ms after the clearance of balanced (three-phase) faults [22,30].

Table 3
Punctual consumption during symmetrical faults.

Symmetrical fault (three-phase)			
	During fault period of 150 ms since the fault is generated	During the first 150 ms from post-fault	
Reactive power produced per cycle (20 ms)	< 60% of the nominal power	< 60% of the nominal power	
Reactive current per cycle (20 ms)		Less to 1.5 times the corresponding current to registered nominal power	
Active power	Punctual consumption	Punctual consumption	Additional consumption < 10% nominal power

- Momentary active or reactive power consumption (< 0.4 pu) is allowed during just the first 80 ms after the start of the fault and the first 80 ms after the clearance of unbalanced (single-phase and two-phase) faults [22,30].

3.2.6. Reactive power control

Similarly to automatic voltage regulation (AVR) in conventional generators, PV and wind power plants need to supply reactive current when the voltage levels are found to be less than 0.85 pu, whereas they should not consume reactive power between 0.85 pu and the minimum voltage that allows a normal operation of the grid. The following need to be fulfilled:

a) The controller will be activated when the voltage ranges outside the normal operation limits
b) Throughout the short circuit incident, the power plant should inject/absorb reactive current according to the action of the voltage controller with minimum saturation levels defined by the curve ABCDE, as illustrated in Fig. 8a.
c) Within the operation limits of $0.85 \leq V \leq 1.15$ pu, the injected reactive current will be based on the voltage control, probably saturating the regulator limits.

3.2.7. Active power control

At the same time a disturbance occurs, the facility should restraint the active current injection within the grey area, as depicted in Fig. 8b. It can be easily seen that the active current limitation is a linear function of the active power that the plant was generating before the fault incident and of the voltage level.

Considering voltage levels lower than 0.5 pu, the active current can be dropped to zero. When current saturation happens, reactive current limitation given by voltage controller saturation precedes over active current limitation. For voltages higher than the normal operation, the facility will try to maintain the active power level prior to the disturbance. In addition, the gain of the active current controller should ensure a dynamic response (90% increment) in less than 40 ms for lower voltage figures of $V < 0.85$ pu and 250 ms for $V > 0.85$ pu.

3.3. Morocco

Grid codes for transmission network are concerned by the control of electrical system which includes frequency and voltage control, as well as farm behavior in abnormal network conditions. In the contrary, small production units which are connected to the distribution network, are concerned by the power quality, the contribution Pcc and the protection system. The common requirements of "Grid Code" include Fault Ride Through (FRT or LFRT) (behavior towards voltage sags), limits in terms of voltage and frequency, regulation of active power and frequency control, regulation of reactive power, in addition to power factor and voltage control. In the case of Morocco, these technical requirements are still under development. Morocco has no written down, standardised grid codes. Rules for connection are determined on a case-by-case basis in agreement with the grid owner ONEE.

3.3.1. General requirements

The Moroccan system operator has various technical specifications in case of disturbances generated at the common connection point. According to the IEC technical report 61000-3-7, the limit values for flicker in high voltage (HV) and extra high voltage (EHV) networks are Pst = 0.8 and Plt = 0.6 [30]. Concerning harmonics, the limit values of the levels of harmonic voltages (in percent of nominal voltage) HV and EHV are presented in Table 5.

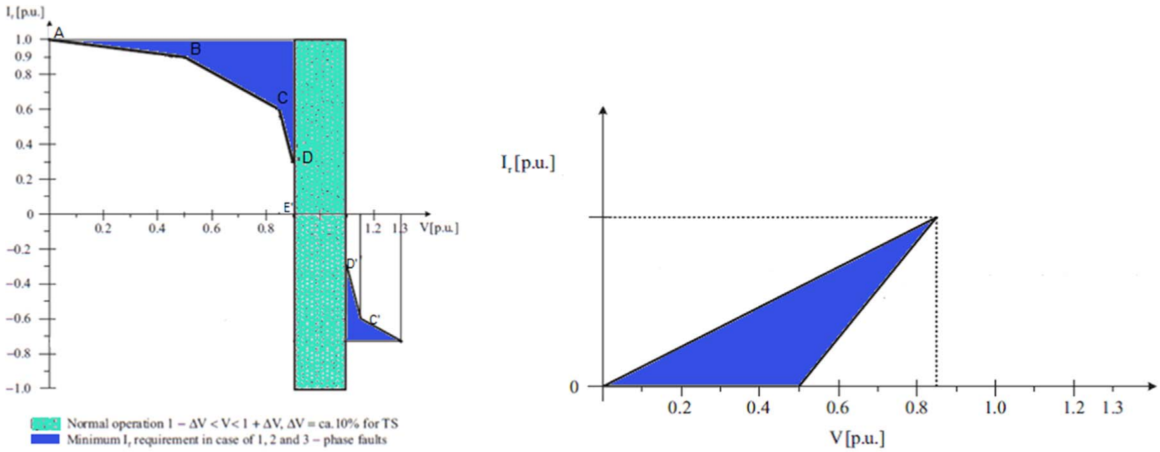
Wind Farms in Morocco must have the ability to withstand voltage unbalance. The voltage unbalance factor is given by the ratio of the negative sequence component of the voltage to the direct component. The unbalance limit value for extra high voltage is 1% [31].

3.3.2. Fault ride through (FRT or LFRT)

The RE park should be strong even in case of voltage dips ranging up to 0% of V_n for some countries for a specific duration. It must at the same time contribute to the rapid restoration of P/Q to the original situation before default after voltage recovery. Some counties require an increase in reactive power during disturbance to support tension (as the case of conventional machines). These characteristic differs from one country to another according to the network and the protection system. Wind farms, in Morocco, must be able to resist voltage dips down to 20% of the nominal voltage over a time span of 600 ms [32], see Fig. 9.

Table 4
Punctual consumption during unsymmetrical faults.

Unsymmetrical fault (two-phase and single-phase)		
	During fault period of 150 ms since the fault is generated and during the first 150 ms from post-fault	Rest fault
Reactive power	Punctual consumptions	< to the reactive power equivalent to 40% of the nominal power registered during a period of 100 ms < 40% of the nominal power registered per cycle (20 ms)
Active power	Punctual consumptions	< to the active power equivalent to 45% of the nominal power registered during a period of 100 ms < 30% of the nominal power registered per cycle (20 ms)



a) b)

Fig. 8. a) Reactive current generation/consumption according to voltage profile, b) Active current limitation.

Table 5
Limit values of the levels of harmonic voltages (in percent of nominal voltage) HV and EHV.

Odd Order not multiple of 3		Odd ranks not multiple of 3		Even order	
Rank h	Harmonic Voltage (%)	Rank h	Harmonic Voltage (%)	Rank h	Harmonic voltage (%)
5	2	3	2	2	1.5
7	2	9	1	4	1
11	1.5	15	0.3	6	0.5
13	1.5	21	0.2	8	0.4
17	1	> 21	0.2	10	0.4
19	1			12	0.2
23	0.7			> 12	0.2
25	0.7				
> 25	0.2 + 0.5 × 25/h				
Total rate of harmonic distortion: 3% en HV -EHV					

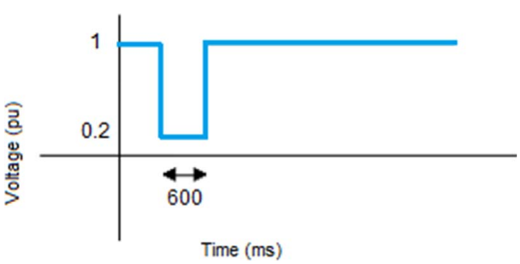


Fig. 9. Fault ride-through curve for wind power.

3.3.3. Active power and frequency control

The park should have the ability to contribute to the regulation of active power according to the frequency deviation from the nominal frequency. In the case of Germany, for example, for frequency greater than 50.2 Hz, the park has to gradually reduce its power output to 40% of power available for each deviation of 1 Hz. The British code expects that the park should have a frequency control system to help primary and secondary control. For Morocco, the park must continue to provide full power regardless of frequency.

3.3.4. Reactive current requirements during voltage dips

The supply of reactive power is important for voltage stability. Its influence on the voltage level depends very much on the power of CC network. There exist several modes of regulation which include connection point voltage, power factor, and reactive power at the connection point. The wind farm should allow the provision and uptake of reactive power. The absorption should be at least between 0 and 0.3Pn and the supply must be at least between 0 and 0.4Pn where Pn is the rated power of the farm [31].

3.3.5. Operating limits for voltage and frequency

Parks must operate continuously for variations of frequencies and voltages that remain within predefined ranges. But also, for a limited time under conditions outside the stated ranges. During small variations in frequency at the grid connection point, generators are required to remain connected and operating. The Moroccan system operator specifies this range. The normal conditions in frequency variation are 50 ± 0.1 Hz while the degraded conditions are 50 + 1 Hz / − 2.5 Hz.

The wind farm must be able to resist voltage dips down to 20% of the nominal voltage over a time span of 600 ms. Fig. 9 presents the Fault ride-through curve for wind power. Concerning the reactive current requirement during voltage dips, grid codes recommend that wind parks provide support for the network by the production of reactive power during failure to maintain and recover the voltage. Even the parks must go beyond 100% of their capacity in terms of production of reactive power. In addition, the wind farm must be able to resist to voltage variation depending on the network type as illustrated in Table 8 [31].

3.4. Egypt – wind power

The requirements specified in the following section are the minimum requirements that should be fulfilled by a wind farm at the grid connection point. The grid operator has the authority to disconnect a wind farm from the grid in case this later does not fulfill the requirements specified in the grid connection code. The reconnection of this wind farm should be agreed with the grid operator. For a stable and safe operation of the grid, the grid operator is authorized to change the following requirements or to provide further ones.

3.4.1. Power quality requirement

All wind farms should comply with the requirements presented in this section. The voltage wave-form quality must be maintained by wind farms at the grid connection point. In the event of voltage deviation from its permissible voltage range at the grid connection point, wind farm shall be capable of delivering available active power according to wind conditions when the voltage remains within the ranges stated in Table 6. Wind farm automatic disconnection from the grid is prohibited.

Table 6
Minimum time periods.

Voltage range	Time period for operation
0.85–0.90 pu	Unlimited
0.90–1.10 pu	Unlimited
1.10–1.15 pu	30 min

Table 7
Maximum level of harmonic voltage distortion.

Voltage level	**Level of harmonic voltage distortion**	
	Odd harmonies %	Total harmonies %
More than 161 kV	1.0	1.5
69.001–161 kV	1.5	2.5
Up to 69 kV	3.0	5.0

Table 8
Maximum level of integer harmonic current distortion in the frequency range up to 2 kHz.

Short circuit ratio	**Maximum integer harmonic current distortion as percentage of I_L**					
	Odd harmonic distortion					**Total* distribution**
I_{sc}/I_L	**< 11**	**≥ 11 to < 17**	**≥ 17 to < 23**	**≥ 23 to < 35**	**≥35**	
< 50	2.0	1.0	0.75	0.3	0.15	2.5
> 50	3.0	1.5	1.15	0.45	0.22	3.75

If required by the grid operator, a wind farm shall be able to disconnect automatically from the grid at stated voltages. Automatic disconnection settings and terms are agreed with the grid operator [33].

In the event of a frequency deviation of the grid from its allowable value, wind farm automatic disconnection from the grid should be prohibited due to the deviation within the frequency range of 47.5 Hz until 51.5 Hz [33].

According to IEEE 519, the maximum level of harmonic voltage and current distortion should be as presented in Table 7. Tables 8, 9, and 10 illustrate maximum level of Harmonic current distortion from wind farms [34]. The total distortion in Table 8 is the maximum level of harmonics current distortion of all generating equipment irrespective of the actual I_{sc}/I_L.

Here Isc is the maximum short circuit current at grid connection point, I_L represents maximum load current (fundamental frequency component) at the grid connection point and the maximum level of even harmonics is 25% of odd harmonics.

The flicker that is caused by wind farms at the grid connection point must be within the limits presented in Table 11 [35].

Concerning the voltage unbalance and fluctuations, wind farms must have the ability to withstand voltage unbalance beyond 2%. The voltage fluctuations are typically caused by the switching operations in a wind farm, such as the start and stop of wind turbine generator and because of inrush currents during wind turbine generator starting. The maximum voltage fluctuation is 5% from the voltage nominal value [33]. The voltage at the grid connection point for wind farms shall not vary for more than ± 5% of nominal voltage.

Table 9
Maximum level of harmonic current distortion in the frequency range above 2 kHz.

Short circuit ratio	**Maximum harmonic current distortion in the frequency range above 2 kHz as percentage of I_L**					
I_{sc}/I_L	2 kHz ≤ f ≤ 3 kHz	3 kHz ≤ f ≤ 4 kHz	4 kHz ≤ f ≤ 5 kHz	5 kHz ≤ f ≤ 6 kHz	6 kHz ≤ f ≤ 7 kHz	7 kHz ≤ f ≤ 9 kHz
< 50	0.3	0.25	0.2	0.15	0.12	0.1
≥ 50	0.6	0.5	0.4	0.3	0.25	0.2

Table 10
Maximum level of inter-harmonic current distortion up to 2 kHz.

Short circuit ratio	**Maximum interharmonic current distortion as percentage of I_L**			
I_{sc}/I_L	**< 0.5 kHz**	**0.5 kHz ≤ f ≤ 1 kHz**	**1 kHz ≤ f ≤ 1.5 kHz**	**1.5 kHz ≤ f ≤ 2 kHz**
< 50	0.3	0.25	0.15	0.1
≥ 50	0.45	0.4	0.25	0.2

Table 11
Flicker factor.

Term	Flicker factor
Short Term (10 min)	Pst ≤ 0.35
Long Term (2 h)	Plt ≤ 0.25

If required by the grid operator, a wind farm shall be able to disconnect automatically from the grid at stated voltages. Automatic disconnection settings and terms are agreed upon with the grid operator [33].

In the event of a frequency deviation of the grid from its allowable value, wind farm automatic disconnection from the grid should be prohibited due to the deviation within the frequency range of 47.5 Hz until 51.5 Hz [33]. The frequency and the voltage limits within which the wind plant shall only connect to the grid are between or equal to 48 Hz and 50.2 Hz for the frequency, while the voltage is between or equal to 0.95 per unit 1.05 per unit.

3.4.2. Active power control

Because of the variations in the grid frequency or the voltage at the grid connection point, the wind plant is not permitted to reduce power output within the range 47.5 Hz up to 50.2 Hz of frequency for the time periods presented in Fig. 10a. In the case of over frequency, grid frequency ranging from 50.2 Hz to 51.5 Hz, active output power of the wind turbine generator must be reduced by 40% of the actual active output power as illustrated in Fig. 10b.

The following Equation gives the reduction of the output power [33]:

$$\Delta P = 0.4\mathrm{PM}\frac{\Delta f}{\mathrm{Hz}} \tag{2}$$

where PM is the actual output power prior to the exceeding of 50.2 Hz grid frequency and Δfis the actual grid frequency minus 50.2 Hz.

The active output power of a wind farm must be reduced on request of the utility grid operator in the following cases:

- Possible risk for a safety grid operation
- Risk of overloading and bottlenecks
- Risk of islanding
- Dynamical or statistical Loss of grid stability
- Maintenance.

To reduce the active output power, the wind farm must have at the grid connection point, an input signal for a set-point value provided by the grid operator. This signal must be followed by the wind plant within one minute in the case of a reduction of active output power. The Wind plant should have the ability to decrease the active output power within

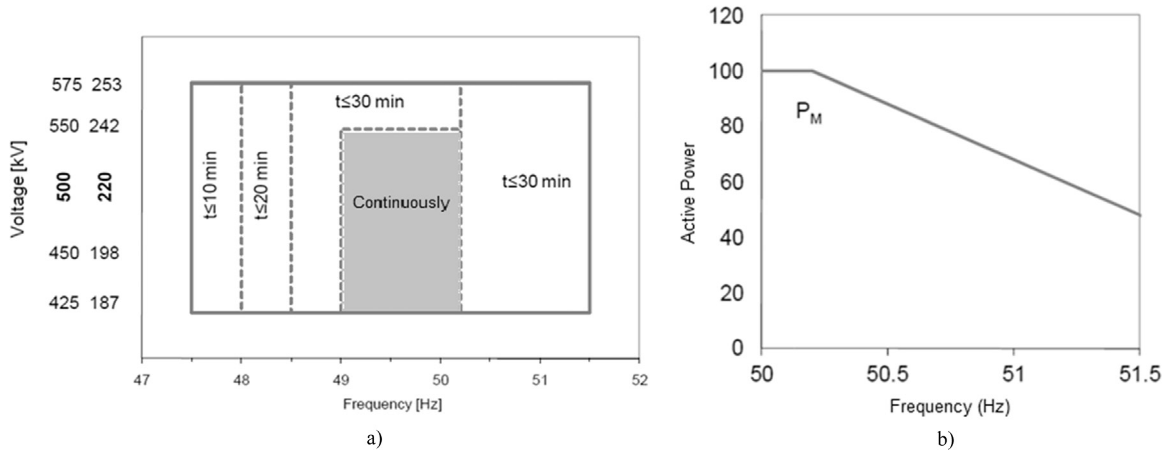


Fig. 10. a) Output power requirements in case of grid frequency and voltage variations, b) Reduction of active power due to over frequency.

steps of maximum 10% of rated power of the wind plant. In addition, the wind farm can be disconnected from the electric grid in case the output power is below 10% of rated power. The active output power reduction must be at a rate of 20% of rated power. The connection agreement of the wind farm agreed on with the grid operator contains more details of the technical solution of the set-point signal [33].

3.4.3. Reactive power control

At the grid connection point, wind plants must have the ability to regulate the reactive power within the range of 0.95 lagging to 0.95 leading at maximum active power as illustrated in Fig. 11. This requirement is applicable to wind farms with high-voltage terminals at grid connection point. Reactive power is controlled by wind plants with the following method [33]:

- Set-point control of reactive power Q
- Set-point control of power factor (cos φ)
- Fixed power factor (cos φ)
- Characteristic: power factor as a function of active power output of the wind farm, cos φ (P)
- Characteristic: reactive power as a function of voltage, Q(U)

The connection agreement determines the mode of operation of reactive power control. To control the reactive power or cos φ, the wind farm must have at the grid connection point, an input signal for a set-point value provided by the grid operator. This signal must be followed by the wind plant within one minute. With respect to reactive power capability below rated capacity of the wind plant, and when operating at an active power output below the rated capacity of the wind farm (P < Pmax), the wind plant shall be able to be operated in every possible operating point in the P-Q Diagram, presented in Fig. 11. Taking into account losses related to the transformed, the auxiliary service power and the wind plant cabling, reactive power supply at the high-voltage terminals must completely match with the P-Q Diagram, even at reduced active power output. The maximum Qcap. and Qind. are determined from the rated power of the wind plant and the power factor of 0.95, see Fig. 11 [33].

3.4.4. Temporary voltage drops

In the occurrence of short voltage drops caused by grid faults, Wind turbine generators are not allowed to disconnect from the grid. In the case of temporary voltage drops, wind generators must ride-through the grid fault without disconnecting from the grid when at least one of the three phase-to-phase voltages is above the curve presented in Fig. 12.

The wind plant is not permitted to disconnect from the grid in case of voltage drops above the curve.

The reactive power or reactive current requirements that must be fulfilled by wind turbine generators during the temporary voltage drop are:

1) In the case of 3-phase faults, the injection of reactive current by the wind turbines must be performed according to Fig. 13. The turbines must inject reactive current for the time period 150 ms until fault clearance [33].

The required minimum reactive current is presented in Fig. 13 and is expressed by the ratio of the reactive current and the nominal reactive current in per unit, against the voltage drop, expressed by the ratio of the actual voltage value and its nominal value in per unit [33]

$$\frac{\Delta I_B}{I_N} = k\frac{\Delta U_r}{U_N} \tag{3}$$

$$\Delta U = U - U_0 \tag{4}$$

Here U_N represents rated voltage, I_N rated current, U voltage during

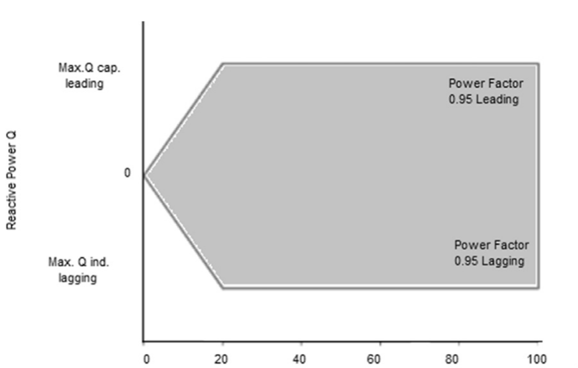


Fig. 11. P-Q Diagram.

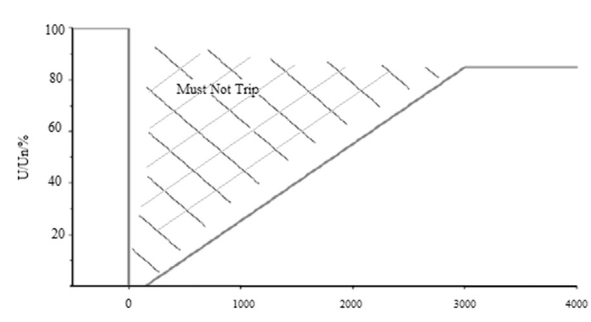


Fig. 12. Fault ride through profile for a wind farm.

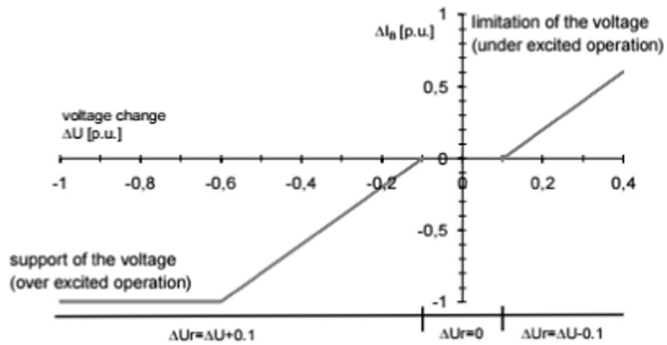


Fig. 13. Current injection during the fault.

fault, I_B is required reactive current change during fault U_0 pre-fault voltage, and U_r stands for relevant voltage change during the fault. The k factor ranges from 0 to 4 while its preferable setting is 2.

2) Wind turbine generators requirements for 2 phase and 1phase faults during the time period 150 ms after the fault entrance until fault clearance are:

- Consumption of reactive power below 40% of rated power
- Consumption of active power below 30% of rated power each grid cycle (20 ms).

The wind farm must, after fault clearance, have an active power that has same level as before the fault's occurrence. This should be reached within a time period of 10 s after fault clearance. The consumption of reactive power after fault clearance must be equal or below the reactive power consumption before the fault.

Two temporary voltage drops may occur in case of non-successful auto-reclosures as illustrated in Fig. 14. The requirements presented in Table 15 should be followed by the wind farm in order to ride-through the two successive voltage drops. The maximum allowed times, when automatic reclosing is applied, are presented in Table 12.

3.4.5. Grid protection

The protection code specifies the grid protection techniques that should be performed by wind farms. The grid protection device in wind farm must have a setting which conforms to the grid protection setting started in the grid code see Table 13.

4. Comparison of grid codes

A comparison of the different technical requirement for the interconnection of wind farm in Spain, Morocco, and Egypt is

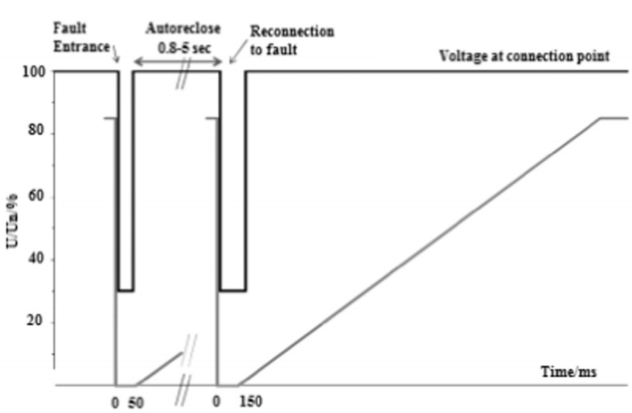


Fig. 14. Voltage drops caused by non-successful auto-reclosure.

Table 12
Auto-reclosure time range.

Case	500 kV-Single phase Trip and reclose	500 kV-Three phase Trip and reclose	220 kV-Three phase Trip and reclose
Fault occurrence	60 ms	60 ms	80 ms
Single phase trip	80 ms		
Single phase reclose after	800 ms		
Evolving fault clearance	200 ms		
Permanent fault	60:80 ms		
Three phase trip		80 ms	100 ms
Three phase reclose		5000:6000 ms	500:100 ms
Reclaim time	Not less than 200 s		

Table 13
Setting of the grid protection.

Function	Setting range	Recommended setting	
		Level	Setting time
Overvoltage U > >	1.00–1.30 U_n	1.20 * U_n	≤ 3 s
Undervoltage U <	0.10–1.00 U_n	0.80 * U_n	3 s
Undervoltage U «	0.10–1.00 U_n	0.30 * U_n	300 ms–1 s
Overfrequency	50–52 Hz	51.5 Hz	≤ 100 ms
underfrequency	47.5–50 Hz	47.5 Hz	≤ 500 ms

discussed in this section. Four requirement categories are being compared which include Fault-ride through requirements, dynamic regulation during fault, requirements for reactive current supply during voltage dips, and voltage/frequency operating range.

4.1. Fault-ride through requirements

The Spanish grid requirements does not permit wind farms to absorb reactive power during and after three phase faults, as well as in the period of voltage recovery after fault clearance. However, the absorption of reactive power can be allowed during a duration of 150 ms after the beginning of the fault, and a duration of 150 ms after clearance of the fault (only if 60% of rated power is not being exceeded). In addition, the active power must not be absorbed by wind farms during the fault and in voltage recovery period after the clearance. Nevertheless, during a period of 150 ms after the beginning of the fault, and a period of 150 ms after fault clearance, the absorption of active power is permitted. The consumption of active power is allowed with a maximum of 10% of rated power during three-phase faults.

Wind farms in Spain must be able to resist voltage dips down to 20% of the nominal voltage over a time span of 500 ms. Similar characteristics can be observed in the requirement governing wind farms connection in Morocco. The minimum voltage level during faults is 20%. However, wind farms are obliged to remain connected for faults duration of 600 ms. The Egyptian grid code requirement is more

Table 14
LVRT characteristics in different grid codes.

Country	Fault duration (ms)	Min voltage level (% of Vnom)	Voltage restoration
Spain	500	20	1
Morocco	600	20	Not Available
Egypt	150	0	3

demanding as it requires wind farms to remain connected during voltage dips down to 0%. It stipulates that wind farms must remain connected to the electric grid for faults duration of 150 ms. During the fault, the maximum voltage sag duration is 3 s. However, if the fault continues longer than the standard clearing time, disconnection of wind turbines is allowable. Table 14 presents a comparison of LVRT characteristics in different grid codes.

4.2. Dynamic regulation during fault

The requirement for capacitive current injection for the Egyptian grid code during faults was shown in Fig. 13. According to this grid code, capacitive reactive current must be supplied by wind farms during three phase faults between 10–60% drop in grid voltage and after the origin of the voltage dip with 150 ms. This supply should be performed with a specific rate of the rated current for each voltage drop of 1%. On the other hand, Spain requires maximum reactive current injection during three phase faults. However, for two and one phase faults, the maximum permitted consumption of reactive power is 40% of the rated power after the fault entrance by a 150 ms period. In addition, the maximum consumption of active power in each grid cycle is 30% of the wind turbine rated power. Concerning Morocco, there is a lack of such relevant information in the Moroccan interconnection requirements.

4.3. Requirements for reactive current supply during voltage dips

The Spanish grid code stipulates that wind farms must stop absorbing reactive power within 100 ms of voltage drop, and are required to inject reactive power within 150 ms of grid recovery. According to the Egyptian grid code, the reactive power must be regulated by wind farms at the grid connection point within the range of 0.95 lagging to 0.95 leading at maximum active power. The absorption in the Moroccan connection requirements should be at least between 0 and 0.3 of the wind farm rated power and the supply must be at least between 0 and 0.4 of the rated power.

4.4. Voltage and frequency operating range

The nominal frequency according to the Spanish grid code requirements is 50 Hz and it permits a large continuous frequency range of 48–51.5 Hz. Below frequencies of 48 Hz, for example, wind farms must not stay coupled to the grid for more than 3 s. On the other hand, the normal conditions of frequency variation for wind farm connected to the Moroccan grid are 50 ± 0.1 Hz, while the degraded frequency conditions are 50 + 1 Hz /−2.5 Hz.

Compared to other countries, Egypt specifies in its grid code that in the occurrence of grid frequency deviation from its allowable value, wind farm automatic disconnection from the grid should be forbidden because of the deviation within the frequency range of 47.5 Hz until 51.5 Hz. Wind plants should only be connected to the grid within a frequency between or equal to 48 Hz and 50.2 Hz, and a voltage between or equal to 0.95 per unit 1.05 per unit.

Another important difference lies in the withstand voltage unbalance required by the Egyptian and the Moroccan grid requirement. Whereas, wind farms in Morocco must have the ability to withstand voltage unbalance of 1% for the extra high voltage, Egypt requires wind farms to withstand a voltage unbalance beyond 2%. In addition, according to the Egyptian grid code, the voltage at the point of common coupling should not change more than ±5% of its nominal value. In the event of over frequency, the active power supplied by wind turbine generator has to be decreased by 40% of the actual output.

5. Recommendations on the development of grid codes for renewable energy in Northern Africa

5.1. Barriers facing North African Countries

This section discusses important technological, economic, regulatory and institutional barriers preventing the emergence of a regional market in North Africa. Collective measures to remove these are summarised below in Table 15.

5.1.1. Physical infrastructure barriers

The majority of North African countries are facing challenges due to rapidly increasing power demand. The lack of generating capacity creates insufficient reserve margin that might lead to critical system operations. Even though there is a significant increase in installed capacity, available capacity to meet the peak demand and maintain an adequate reserve margin remains the key component. Hence, during peak demand, systems are under huge pressure because they run under very small reserve margins which are negative in most countries. This issue could lead to unstable system performance and ineffective operations.

Possible implications caused by insufficient generation capacity are summarised below:

- Reliability risk: This is a system security issue. It occurs when the system is unable to meet the demand or when it does not securely handle unexpected disturbances. Therefore, to maintain the security of supply at the national level, operators of power grids in North African countries could be required to disconnect cross-border interconnections and to apply load shedding actions.
- Stability Risk: operators have to maintain system synchronism by controlling voltage and frequency and hence maintaining stability of the synchronized power grids. Consequently, they have to achieve both active and reactive power equilibrium in order to maintain frequency and voltage respectively. The lack of adequate reserve margin, in most North African countries, leads to imbalance between the demand and the generation; which creates non-equilibrium in active power and thus results in deviation from standard frequency. Even if Egypt has a synchronized system, the share of surplus power to boost spinning reserve is limited because of the deficiency of available generating capacity. In addition, rigorous frequency control would be required to maintain the standard frequency of the system due to the lack of generating capacity.
- Low system inertia: Some North African power grids have very low system inertia. The synchronization to high inertia system in these power grids is very complex. This issue would involve some major reinforcement to secondary frequency control at the generation side before full synchronization of the entire North African power grids.

5.1.2. Transmission network access

Transmission operation is managed as part of a vertically integrated system, under a ministry in most of the power grids in North African countries. Third party access to power grids has been blocked by the lack of regulatory rules and the organizational attachment of the transmission. Consequently, to attract market players such as industrial consumers, IPPs, and traders would necessitate transparent and non-discriminatory market rules. The organizational inflexibility barrier contributes to the slow development of North African countries' electricity market. The development of the market and the synchronization process would be facilitated by the independence of the transmission, with well-defined responsibilities and decision-making authority over system operations.

5.1.3. Non-binding trading arrangements

The trading arrangements currently used between the system

Table 15
Summary of challenges facing North African Countries with recommendations.

Challenges	Recommendations
Regulations:	– Harmonize electric grid codes
– Lack of standards and norms	– Establish a coherent regional regulatory framework (conditions for electricity trade, regulation, etc.)
– Non-harmonized regulations	
– Low third-party access to the grid	
– Low capacity of the electrical grids	
Technical	– Strengthen existing inter connections and extend to countries not yet connected (e.g. Mauritania)
– Weak interconnection capacity	
– Organization and management of interconnections	
Institutional	– Strengthen the regional capabilities for integration of RE in electrical networks (regional plan for connecting RE to the grid)
– Low command of technologies	
– Lack of competence	– Adopt a common negotiating position with the EU
Economic	– Gradual reduction of subsidies
– Management of price distortions in the sector	– Communication and public awareness
– Fossil fuel subsidies	– Financing mechanisms to be implemented

operators of the synchronized power grids are bilateral. Agreements do not include binding articles for trading electricity in bulk amounts. Most of them appear to limit electricity trade to exchanges during emergency operations. Therefore, the current trading arrangements of North African countries limit the attractiveness of electricity trade.

5.2. Recommendations

This section summarises recommendations towards the development of North African grid codes. Those that are suitable for each country's specific conditions and for the integration of renewable energy.

5.2.1. The need for grid codes

In the past, and in many countries still, the electricity sector has been a vertically integrated and state-owned monopoly including power generation, distribution and supply. In this situation, the specification of power plant and equipment connected to the grid was selected according to need and cost-benefit analyses. Specifications included location, fuel type, control systems and other technical details.

With the splitting up of state-owned monopolies into multiple companies with a separation of roles and responsibilities (unbundling) and the introduction of competition through market liberalization, many different companies become active in the sector, including power generation companies. This has led to a need to specify general rules and requirements, i.e. grid codes: In an unbundled electricity sector, grid codes are needed to clarify the distribution of responsibilities, and to ensure the safe, secure and economic operation of the grid.

Grid code requirements for generators are particularly important with increasing renewable energy integration. Renewable generation changes fundamentally the power system; and it is important that critical issues are anticipated and avoided in a timely fashion. Ireland is an example where wind power was allowed to develop with inadequate connection requirements, leading to an abrupt stop in 2003 of wind integration due to system stability concerns. To release this moratorium a grid code for wind was developed. Moreover, renewable generation is often made up of more and smaller plants, making it inefficient to specify requirements on a case-by-case basis.

5.2.2. Education

Proper understanding of what is needed and what is possible is essential in any development process. For grid codes, this involves cross-disciplinary education where all actors achieve a certain level of understanding of the power system and each other's concerns. This includes generation technologies, operational strategies, economics, laws, regulations, and other fields. For example, system operators should learn about technical capabilities and limitations of renewable energy. Universities have an important role to play in this, producing graduates with high expertise in the relevant disciplines. But expertise in each area is not sufficient in itself. It is crucial that this expertise is brought together and shared amongst all grid code stakeholders.

5.2.3. Stakeholder involvement

This point is a continuation of the one above on education. In order to arrive at best decisions with good compromises, it is important that the views of all stakeholders are shared and discussed. This may happen in multiple ways. Formal discussions and negotiations are only a part of it. To facilitate this process, there should be one or more forums or working groups; where everyone are brought together to share views and ideas. Informal meetings can be very efficient in order to explore new ideas.

Standardisation agencies with experience in developing national standards, such as e.g. IMANOR in Morocco, may have a natural role in this. A standardisation committee tasked with writing a national standard for grid connection may be a good basis for a national grid code.

5.2.4. Governance

How the development and maintenance of grid codes should be governed is a question that needs to be answered. There should be a well-defined, transparent and open process, involving relevant stakeholders as pointed out above. The grid codes will have cost impacts on users and stakeholders that will affect customers' energy bills. The costs may also determine the competitiveness of different market actors, such as generators. In order to balance different interests, good governance of the grid code development process is important.

Guiding principles could be:

- A code Panel should represent all stakeholders with independent chair.
- Any stakeholder should be able to raise a modification.
- Informal workshops are a good way to test challenges, ideas or proposals for changes to the Code.
- Working groups with experts should be appointed where appropriate.
- Changes should be consulted on.
- Consultation should be meaningful and take account of responses.
- The National or Regional / EU Regulator should have final decision, if industry does not agree on a change.
- Changes should not be implemented retrospectively.
- Changes should allow sufficient notice period for new requirements to be designed, specified, contracted and delivered.
- There must be an option for exemptions.

5.2.5. Standardisation

Standardisation of codes means the existence of well-documented

and predictable grid codes that apply to all within a country or region. Power generation from wind and solar energy is typically made of small generating units, i.e. wind turbines or photovoltaic arrays. A wind turbine is not generally custom-made for a particular installation. The application of standard solutions and economy of scale is important for the minimisation of manufacturing costs. This means that when manufacturers design their generating units and systems, they must anticipate and account for different conditions, including different grid connection requirements. In order to allow for designs that can fit in different markets, it is critical that the grid connection requirements are known i.e. well documented and not subject to sudden changes. Predictability is probably more important than similarity, although it helps that grid codes are formulated using the same nomenclature and that the requirements are largely the same. Predictable, standard requirements helps the supply industry to know what is needed, and therefore helps the creation of a healthy supply chain that can provide components at minimal costs, suitable for a big market.

Standardisation of requirements moreover contributes to a level playing field, where different developers and technologies can compete without unfair bias.

5.2.6. Harmonisation

Harmonisation of codes means that grid codes in different countries or regions are formulated with the same technical definitions and are largely the same, in terms of scope and structure. Specific requirements may be different, as appropriate for each individual power system. Harmonisation of grid codes is another step from standardisation within a single area.

In Europe, there is an on-going effort to harmonize grid codes to support a well-functioning single electricity market. This process is driven by the ENTSO-E umbrella organization for European TSOs. These so-called Network Codes provides a structuring of codes, definitions and basic requirements that can be readily adopted by North African countries. This will help in the communication and transfer of knowledge and technology. Although not members of ENTOS-E, it is therefore recommended that North African countries align with this process.

5.2.7. Grid code vs. market solutions

Codes are not the only option to achieve a safe, secure and economic operation of the grid. It should also be investigated of what can be achieved through market-based solutions, i.e. an ancillary services market. A market enables actors to participate on a paid-for basis, earning revenue by supporting grid stability. As in markets, in general, it allocates resources in an efficient way, allowing generators and other facilities to benefit from their individual strengths in terms of controllability and flexibility. However, this requires that the ancillary services market is well designed and that there is a sufficient number of potential participants and competition that it will actually function. This is probably easier in already well-established liberalised electricity markets than in newly markets.

The main difference is that grid codes demands universal technical capabilities, whereas ancillary services markets pays for technical capabilities on a voluntary basis. Codes put the same requirements on all generators, disregarding the extra costs it puts on different types of generators and whether all requirements are needed in all locations. A market that is more flexible, may ask for different capabilities in different areas, and may change more rapidly over time as needs change.

The recommendation here is that market solutions should be considered as an alternative to strict grid codes. Grid codes are clearly important and for many requirements the only viable way to ensure that those will be satisfied, but for less universally needed capabilities, codes may be inefficient, raising the costs of electricity supply unnecessarily, and hindering renewable energy integration. For example, need for reactive power support is locally dependent and it is better to pay for this where it is needed, than requiring the capability to do so from all generators everywhere in the grid.

5.2.8. Scope and structure

Different countries have grid codes with different scopes, and when developing new codes it is a relevant question how much they should include. For example, should they also cover electricity market design and market rules? In order to simplify communication and facilitate harmonisation with Europe, it is recommended for new grid codes being developed in North Africa that the structure of the ENTSO-E Network Codes already adopted.

5.2.9. What should be included in the code

The *required* behavior of generators and other facilities connected to the grid should be something less than the *desired* behavior. Although it may be tempting to add requirements or make requirements stricter for the sake of improved system safety and security, there is a balance due to the costs of imposing too many requirements. Requirements that have little benefit should not be included in the code. In general, before defining requirements, it is important to learn about what is really needed. Too many standard requirements are inefficient, giving an unnecessarily costly power system.

It is always an option to leave things out of the code, and instead impose additional requirements on a case-by-case basis when needed. This is against several of the recommendations made above, but is worth keeping in mind as a counterweight to the temptation of including ever more requirements in the codes. Grid codes are not good at any cost.

5.2.10. Room for exemptions

In order to allow innovations, it must be possible to be exempted from grid code requirements in certain circumstances. This is highly important for example for demo projects testing new technology in full scale. A reasonable condition for being granted exception is that the facility is relatively small and poses no risk to system stability.

6. Conclusion

This document has given an overview of grid codes including their historical context and current status of development in Europe and North Africa. Particular emphasis in the report has been on what is relevant for renewable energy generation such as fault ride through, voltage control, reactive power control, and frequency regulation. Typical grid code technical requirements were introduced and more details given for what is presently the situation in Spain, Morocco and Egypt. Spain has elaborated technical requirements regarding PV installations and well established grid code for wind energy installations.

Europe is in a process of harmonisation of grid codes to facilitate closer integration of electricity markets. As part of this process, ENTSO-E has published wide-ranging network codes that will be legally binding in the EU. These codes affect particularly cross-border network and market issues. This has implications also for North African countries which has or will have connections to European countries.

As North African countries have ambitions to integrate new renewable plants with several thousands of MW, they are in a clear need to develop grid codes or standardised rules for connections, with the aim to ensure safe, secure and economic operation of the grid, taking into account the special characteristics of fluctuating renewable energy sources and new technologies for grid connection. This will help Arab countries move gradually from the current status of their electricity markets; to an integrated regional market that will enable efficient and open participation by all market players in cross-border trade.

Finally, this report has proposed a number of recommendations for the further development of grid codes suitable for renewable energy

integration in Northern African countries. Among the main recommendations for the North African countries are those proposed for transitional market design, that will go a long way toward meeting these countries' objectives relating to reliability, sustainability, and security of supply; without the need for significant national power sector reform. Others are directly related to the mini road map of what should be done in North Africa, in Morocco and Egypt to develop grid codes.

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